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Author:

Charles J. Moretti

Contractor:

University of North Dakota
Department of Civil Engineering
P.O. Box 8115
Grand Forks, North Dakota 58202

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AN EVALUATION OF DISPOSAL AND UTILIZATION OPTIONS FOR ADVANCED COAL UTILIZATION WASTES

CHARLES J. MORETTI
Assistant Professor of Civil Engineering
University of North Dakota
Grand Forks, North Dakota

INTRODUCTION

If the United States is to continue to effectively use its substantial coal reserves, new "clean coal" technologies must be developed to improve power production efficiency and reduce emissions from power plants. The U.S. Department of Energy through its Clean Coal Technology Program is assisting the development of innovative technologies by the power industry. Because of the combined efforts of the federal government and private companies, several new technologies have been demonstrated in the past ten years.

Solid wastes produced by clean coal technologies, in most cases, will have significantly different properties compared with solid wastes produced by conventional coal combustion processes. This is because a common goal among all of the clean coal processes is to reduce air pollution emissions, so most use some type of sorbent material to enhance sulfur capture in the combustion gas. Spent sorbents from these processes usually have high calcium and sulfur contents, and they may or may not be mixed with other wastes such as fly ash or bottom ash.

Successful disposal practices for solid wastes produced from advanced coal combustion and coal conversion processes must provide for efficient management of relatively large volumes of wastes in a cost-effective and environmentally safe manner. At present, most coal utilization solid wastes are disposed of using various land-based systems, and it is probable that this practice will continue to be widely used in the future for advanced process wastes.

In order to gain information about wastes produced by advanced coal utilization processes, a research project is being conducted to characterize the geotechnical and geochemical properties of advanced coal process wastes. The University of North Dakota Energy & Environmental Research Center (EERC) analyzed 34 of these wastes for their bulk chemical and mineral compositions and for the disposal-related physical properties listed in Table 1.

This paper discusses potentially useful waste management practices for eight bulk waste samples obtained from four different clean coal processes:

- Gas reburning with sorbent injection (GRSI)
- Pressurized fluidized-bed combustion (PFBC)
- SO_x , NO_x , RO_x , BOX (SNRB)
- Coal Reburning (CR)

All four processes have been demonstrated at either full-scale or pilot-scale facilities in the United States. Since the properties of advanced process wastes are different from conventional coal combustion wastes, an analysis was performed to identify any potential problems that could occur when standard, off-the-shelf waste management technologies are used for handling and disposal of advanced process wastes. When potential problems were identified, possible alternative technologies were evaluated.

DISPOSAL OF CLEAN COAL PROCESS WASTES

Gas Reburning Sorbent Injection Process

The objective of the GRSI process demonstration was to reduce 60% of the NO_x emissions by gas reburning and to capture 50% of the SO_2 by sorbent injection. It is expected that the GRSI process can be used for either tangentially fired or cyclone-fired boilers. The GRSI process operates by supplying 80% to 85% of the total fuel to the main burner of a coal-fired boiler. The remaining 15% to 20% of the fuel is supplied as natural gas to a reburn zone located above the main burner. The air-to-fuel ratio in the reburn zone is controlled so that reducing conditions are created. This promotes the conversion of NO_x created in the main burner to nitrogen and water. Additionally, a calcium hydroxide sorbent is injected into the boiler above the reburn zone for SO_2 capture. Before the combustion gas leaves the boiler, enough air is added to complete the combustion of the natural gas. After the flue gas leaves the boiler, humidification water is added to promote further SO_2 capture in the flue gas. Some of the spent sorbent is collected with the bottom ash and the rest is collected with the fly ash¹.

Two solid waste streams were sampled from a GRSI demonstration run. Sample GRSI-BA was a crushed bottom ash collected from a pulverized coal-fired boiler, and Sample GRSI-FA was a fly ash collected from an electrostatic precipitator.

The GRSI bottom ash was a granular material similar to a conventional pulverized coal process bottom ash. Since a calcium hydroxide sorbent was being injected into the

boiler during the test run, this bottom ash did contain higher levels of calcium and sulfur than would be expected in a conventional bottom ash produced from the same coal. (The results of bulk chemical analyses are contained in Table 2.) Still it should be possible to dispose of the GRSI bottom ash using procedures similar to those used for conventional bottom ashes. This often involves either sluicing the bottom ash to a settling pond or trucking it to a landfill. Although the GRSI bottom ash was slightly self-hardening, it still should be possible to transfer the waste by wet sluicing as long as the material is kept moving and not allowed to accumulate in the sluice channel. (See Table 3 for a summary of the self-hardening and self-heating potentials of the wastes.)

As an alternative to disposal, it should be possible to utilize the GRSI bottom ash for many of the same by-product applications for which conventional pulverized coal bottom ashes are used.

The important considerations for selecting appropriate handling and disposal procedures for the GRSI fly ash are that 1) the material is self-hardening and 2) it produces a leachate with a relatively high pH. Even though the material was self-hardening, it did not set up quickly and so would probably not pose any problems for conventional dry transfer systems and conditioning operations. However, care should be taken not to let the conditioned waste set up in the trucks while being transported to a disposal site.

Since the GRSI fly ash produces a high-pH leachate, it will probably be best to handle this material with as little added water as possible. The waste should, therefore, be transferred in a dry form and conditioned with just enough water to achieve its maximum compacted density.

Pressurized Fluidized-Bed Combustion Process

The objective of the PFBC process demonstration was to verify the performance of the technology in a combined-cycle application. The process is expected to remove greater than 90% of the SO_2 from the combustion gas, achieve a NO_x emission level of 0.2 lb/MMBtu, and achieve a power production efficiency of 38%. The PFBC process uses a bubbling bed configuration in which crushed coal and dolomite are injected into the combustor. The coal is burned to produce steam, and the dolomite is a sorbent for SO_2 capture. During operation, bottom ash is removed from the combustor and fly ash is carried out of the combustor with the flue gas. The flue gas first passes through a set of cyclones that collect about 98% of the fly ash. The flue gas that leaves the cyclones passes through a turbine to generate additional electric power¹.

Three solid waste streams were sampled from a PFBC demonstration run. During the run that produced these wastes, a dolomite sorbent was injected into the combustor. Sample PFBC-BA was a granular bottom ash collected from the bed of the combustor. Samples PFBC-CA and PFBC-FA were fly ashes removed from the flue gas with a mechanical cyclone and an electrostatic precipitator, respectively.

The PFBC bottom ash had similar properties to a conventional pulverized coal combustion bottom ash. However, because of the spent sorbent, it did contain 8.7% SO_3 , which is a much higher sulfur content than would typically be found in a conventional bottom ash. The waste was not self-hardening or self-heating, and so it should be possible to handle and transport it using the same types of systems that are currently being used for conventional bottom ashes. The PFBC bottom ash could be utilized for a fill material, but if it is, care must be taken with applications where the ash could corrode buried concrete pipes and footings.

Both PFBC fly ashes were self-hardening, although neither set up very quickly. The cyclone ash actually developed a compressive strength of 2325 psi in 28 days, which is similar to the strength developed by a low-strength concrete. Since the fly ashes behave this way, care should be taken while storing or transporting conditioned materials for an extended time period not to allow it to set up in trucks or other containers. Both of the PFBC fly ashes contain too much SO_3 to be used for cement replacement; however, they could be used as fill material in some situations. They should also be well suited for uses such as soil stabilization, soil amendment, sludge stabilization, and pavement base course.

Coal Reburning Process

The objective of the CR process demonstration was to reduce NO_x emissions from a coal-fired cyclone boiler by greater than 50% with no serious impact on cyclone boiler operation. The process involves injecting 20% to 30% of the coal input to the boiler into a reburn zone above the main cyclone burner. Pulverized coal is injected into the reburn zone with only enough air to achieve partial combustion of the coal. This arrangement creates reducing conditions in the reburn zone and promotes conversion of the NO_x produced by the main burner to nitrogen and water. Combustion is completed in a burnout zone above the reburn zone by adding more air to the boiler¹.

Two solid waste streams were sampled from a CR demonstration run. Sample CR-BA was a slag-type bottom ash produced from a cyclone-fired boiler, and Sample

CR-FA was a fly ash collected with an electrostatic precipitator. Since a sorbent was not used with the CR process, both the bottom ash and the fly ash were very similar to wastes produced from a conventional cyclone-fired boiler. Thus it should be possible to handle and dispose of these wastes using the same systems currently being used for conventional cyclone-fired boilers. The CR wastes seem to have high utilization potential. The fly ash, which had a loss on ignition of less than 0.1%, appeared to meet the American Society for Testing and Materials (ASTM) C618 specification for use as a cement replacement additive. The results of the relevant tests are shown in Table 4. The bottom ash could possibly be marketed as an aggregate for bituminous pavement, a blasting grit, and a road deicing material.

SO_x, NO_x, RO_x, BOX Process

The objective of the SNRB process project was to demonstrate that a high level of reduction of SO_x, NO_x, and particulate emissions can be achieved with a single postcombustion, high-temperature baghouse. The SNRB process is intended to be used in retrofitting power plants burning high-sulfur coal. The SNRB process uses hydrated lime sorbent injection into the flue gas to capture SO₂ and ammonia injection to capture NO_x. After sorbent and ammonia are injected, the flue gas passes through a high-temperature baghouse containing ceramic fiber filter bags. The ammonia in the flue gas reacts with NO_x in a selective catalytic reduction bed located in the baghouse filters. The reaction products are nitrogen and water. Spent sorbent and fly ash are trapped by the filter bags and collected as a dry mixture in an ash hopper located at the bottom of the baghouse¹.

One solid waste stream was sampled from a SNRB demonstration run. Sample SNRB-FA was a fly ash collected in a baghouse. This waste had a high calcium content and a fairly high sulfur content because a calcium hydroxide sorbent was used. Even though the waste had a high calcium content, it did not display significant self-heating behavior. The reason the waste was not self-heating was that the temperature in the flue gas duct was not high enough to dehydrate the unreacted calcium hydroxide to calcium oxide. Therefore the sorbent in the fly ash did not rehydrate, with an accompanying release of heat, when the waste was conditioned with water.

It should be possible to handle and transport the SNRB fly ash with the same types of equipment and systems that are currently being used for conventional coal combustion fly ashes. The waste is moderately self-hardening, and so care should be taken not to let conditioned material set up in storage bins or transport vehicles. It also should be noted

that the waste has a fairly low compacted density. The low density is probably due to its high calcium content. A low compacted density means that this waste will require a larger landfill volume to dispose of a unit mass of material than would be required for a waste with a higher compacted density. Since the SNRB fly ash has a high acid-neutralizing capacity, it could possibly be utilized as a soil amendment in situations where an acidic soil is to be neutralized.

CONCLUSIONS

Eight solid wastes produced from four advanced coal utilization processes were characterized. The advanced processes that supplied samples included a gas reburning sorbent injection process, a pressurized fluidized-bed combustion process, a coal reburning process, and a SO_x, NO_x, RO_x, BOX process. The waste samples ranged from fairly coarse materials such as bottom ashes and spent bed materials to very fine materials such as fly ashes and cyclone ashes.

Based on the results of the waste characterizations, an analysis of appropriate waste management practices for the advanced process wastes was performed. The analysis indicated that it should be possible to use conventional waste management technology to handle and dispose of all eight of the advanced process wastes studied. However, some of wastes did possess properties which would present special problems for conventional waste management systems. Several of the wastes were self-hardening materials, and one was a self-heating material. Self-hardening is caused by cementitious and pozzolanic reactions that occur when water is added to the waste. All of the advanced process wastes set up fairly slowly (in a matter of hours or days rather than minutes), so they can be handled with conventional management systems if care is taken not to allow conditioned materials to set up in storage bins or transport vehicles.

Waste self-heating is caused by the exothermic hydration of lime, which occurs when the waste is mixed with conditioning water. If enough lime is present, the temperature of the waste will rise until the water begins to boil and steam is produced. It was recommended that the self-heating wastes be conditioned under controlled conditions so that the heat and steam can be safely dissipated before the material is transported to an ultimate disposal site. In order to get the self-heating wastes wet enough to fully hydrate when they are conditioned, they must be initially mixed to the consistency of a wet slurry. As the lime hydrates, the waste will gradually dry out. The process takes about 20 minutes.

Table 2. Major Element Composition* of the Advanced Process Wastes²

Sample Designation	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O
GRSI-FA	32.1	12.1	8.0	28.6	2.8	1.4	0.7
GRSI-BA	43.0	15.0	16.9	11.0	1.2	1.4	0.7
PFBC-FA	26.5	13.8	8.0	16.7	9.3	0.4	2.2
PFBC-CA	20.4	7.5	8.5	21.5	15.1	0.2	1.0
PFBC-BA	5.9	2.1	3.2	31.0	23.5	0.0	0.0
CR-FA	36.7	16.7	20.0	8.0	1.3	0.8	0.0
CR-BA	44.0	17.9	21.0	21.0	0.6	0.4	0.0
SNRB-FA	11.4	4.5	5.5	43.0	1.8	0.1	0.3
	0.3	0.3					

* All elements are reported as oxides on a weight percent basis.

Table 3. Estimated Self-Heating and Self-Hardening Potentials of the Advanced Process Wastes²

Sample Designation	Waste Self-Heating Potential*	Waste Self-Hardening Potential**
GRSI-FA	Moderate	Moderate
GRSI-BA	None	Moderate
PFBC-FA	Low	High
PFBC-CA	None	High
PFBC-BA	None	None
CR-FA	Low	High
CR-BA	None	None
SNRB-FA	Low	High

* Self-heating potential was estimated from the maximum waste temperature after the waste was mixed with water. None: <70°F, Low: 70°F to 100°F, Moderate: 100° to 200°F, and High: >200°F.

** Self-hardening potential was estimated from the 7-day compressive strength of the wastes. None: <5 psi, Low: 5 to 10 psi, Moderate: 10 to 50 psi, and High: >50 psi.

Table 4. Comparison of Waste Properties to ASTM C618 Specifications²

Sample Designation	Total SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ Content (wt%)	SO ₃ Content (wt%)	Pozzolanic Activity Index (% of control)	% Retained* on a No. 325 Sieve (wt%)
GRSI-FA	52.2	8.0	83	0
GRSI-BA	74.9	2.4	49	92
PFBC-FA	48.3	23.7	64	20
PFBC-CA	36.4	10.3	71	83
PFBC-BA	11.2	8.7	41	98
CR-FA	73.4	2.2	85	10
CR-BA	82.9	0.0	ND**	99
SNRB-FA	21.4	12.0	81	0

* Percent waste retained on a #325 sieve was estimated from the particle-size analysis.

** No data. These wastes were not tested for pozzolanic activity.

Note: Some requirements to meet ASTM C618 specifications include:

- Total SiO₂ + Al₂O₃ + Fe₂O₃ content must be >70% for Class F ash and >50% for Class C ash.
- SO₃ content must be <5%.
- Pozzolanic activity index (for cement) must be >75% of control after a 28-day cure.
- Percent retained on a No. 325 sieve cannot exceed 34%.

The utilization potentials of the advanced process wastes were also evaluated based on their physical properties, bulk chemical compositions, and mineral compositions. Waste utilization is important, because if the waste is sold it will not require ultimate disposal. Only one of the eight materials studied appeared to be suitable for use as a pozzolanic concrete additive. However, many of the wastes appeared to be suitable for other less profitable uses such as blasting grit, fine aggregate for asphalt concrete, road deicer, structural fill material, soil stabilization additives, waste stabilization additives, landfill cover material, and pavement base course construction.

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1. Electric Power Research Institute, Atmospheric Fluidized-Bed Combustion Waste Management Design Guidelines, EPRI CS-6053, 1988.
2. Electric Power Research Institute, Coal Ash Disposal Manual, EPRI CS-2049, 1981.
3. Electric Power Research Institute, Coal Combustion By-Products Utilization Manual, EPRI CS-3122, Vol. 1, 1984.

Table 1. Tests and Analyses Included in the Waste Characterization Protocol²

Poured Bulk Density	Pozzolanic reactivity
Packed Bulk Density	Permeability
Particle Specific Gravity	Moisture-density relation
Moisture Content	Particle analysis
Compressibility/Consolidation	Blaine fineness
Heat of Hydration	Specific surface area
Angle of Internal Friction	Unconfined compressive strength
Particle Species Analysis	X-ray diffraction
Scanning Electron Microscopy	Thermogravimetric analysis
Photographs	Sulfur forms analysis
Chemical Point Counts	Bulk chemical analysis
Angle of Repose	Chloride analysis